International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 10, Issue 1, Feb 2020, 315–326

EXPERIMENTAL COMPARATIVE ANALYSIS OF A SINGLE AND MULTI RECEIVERS OF A SOLAR CAVITY COLLECTOR

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ABSTRACT

Improvement on the Flat Plate Collector [FPC] design is much needed so as to improve its performance. Hence, one such development and improved version is a Solar Cavity Collector [SCC]. It is an upgraded and advanced version of FPC. A cavity configuration, in- general is used of extent in Fresnel- lens type and concentrated type collectors. But, it has been experimented for the development of FPC to extend its performance enhancement. For improving the heat transfer characteristics, cavity type collectors are the better choice, since it can be used during cloudy days, where intermittent nature of the solar energy is inevitable. It gives the better results even if the solar radiation that has received is of intermittent type. An SCC of outer radius = 16 mm (single cavity) have been concentrically positioned and located at the centre of SCC of 50x50 mm size of a metal box. The same procedure is followed for the fabrication of all five cavities. Then, the provisions for outlet and inlet water pipes have been fabricated. After fabrication of SCC has been completed, the same is experimented to test the optimal performance of SCC. The Experimental investigation was carried out for single, three and five numbers of receivers being used in SCC to heat the water of the cavity collector, to finding out which type of receivers would give better results. Also to investigate, the better rate of heat exchange between these kinds of receivers usage in SCC. Copper is used as a receiver material. It has been concluded that the single receiver gives better results than the other.

***KEYWORDS:** Solar, Cavity, Cavity Collector, Cavity Receiver, Single Receiver & Multi Type Receiver*

Received: Nov 28, 2019; **Accepted**: Dec 18, 2019; **Published**: Jan 10, 2020; **Paper Id.**: IJMPERDFEB202027

INTRODUCTION

The fossil fuel combustion causes major pollution problems of many areas, such as air & water contaminations resulting in causing diseases and also affects ecological system. Also, it results in global warming scenario and increases the earth's global temperature. Solar energy has been a right candidate or a clean, abundant, inexhaustible, non-polluting, more effective and efficient renewable energy source. Solar energy radiations has been collected and converted into thermal energy for air and water heating applications with help of any type of solar collectors.

Flores et al. (1) reviewed that the influences of heat transfer of radiative component inside a cubic cavities. They reported about the heat transfer of radiation mode plays major role when compared to a convection mode. A model of mathematical type has been developed and study was carried with different solar coatings absorptances. The effect of multiple refection effect inside a macro type cavity has been developed by Demichelis and Russo(2). They design the cavity optically and enumerate the cavity effect for different concentrating type solar collectors. Reyes et al.(3) presents an optical designing performance of FPC of non isothermal type. Also, they explain about

how to create a thermo economic model with annual cost of operation of an air heater using dimensionless parameters. Melchior et al. (4) explain about cavity receivers, containing an absorber of tube type has been developed, and the same is validated with experimentally too. The solar reactor contains a ceramic made absorber, which utilizes high thermo chemical process. This can be done for the achievement of higher temperature generation applications, namely H2 generation/production.

Bairi (5) form the different cavity of parallelogram in shape, and he explains about several angles of inclinations with heat transfer mechanisms flow through with passive and also active walls. He tried with different correlation of Nusselt number. Hahm et al. (6), this paper focuses with a cone shaped cavity collector and receiver, which has a different aperture sizes (small & large). They explain about reactions of heat radiation, which escapes from the smaller & larger aperture sizes. That is, rejection rate is higher in the case of smaller apertures. Similarly, rejection rate is lesser in the cavity, but it restricts the rays coming inside to the cavity in the case of larger aperture size. Singh et al. (7) explained about the heat transfer from the cavities depends upon the cavity shape, aspect ratio and boundary condition of the wall. Also, they analyzed about the shape of the cavities such as square, cylinder and rectangular shaped cavities of CPC type collector. Results obtained by improving the performance with the help of reducing convection mode of heat transfer.

Prakash et al. (8) reviewed the thermal losses and optical losses inside the parabolic dish type cavity receiver system. Experiments were conducted with inlet fluid temperatures varying between 50oC and 75oC. The inclination angles of 0o, 30o, 45o and 90o have been modified by using CFD fluent software. They found convection mode of heat loss increases with receiver temperature, and it decreases with the inclination angles of the receiver. Kribus et al. (9) uses an experiment, in which, it has two heating stages, namely low temperature and high temperature stages. Results indicating that the convection mode of heat loss was reduced and also achieved by minimizing the partition losses. Designing and testing of a solar water heater was reviewed by Cruz et al. (10). Also, they work with various tilt angles in Portugal country. They use thermal stratification inside the cavity structure and saved energy more, with a tilt angle of 45 o was actually employed in their present study.

Lakshmipathy. B and Sivaraman. B (11) have conducted an experiment with different inclination angle to obtain the optimum performance of SCC. It shows that a maximum efficiency around 59% was obtained with 11o inclination angle and while 20o inclination yields an efficiency of 56% only. Hence, it was found that the optimum level of tilt angle for cavity collector was 11o.Lakshmipathy.B and Sivaraman. B (12) have conducted the Performance procedure and optimization techniques on its working parameters of the SCC. They concluded that, the Copper as the receiver material gives more efficiency than the Aluminum. At higher flow rates, multi receiver would be a better choice to give optimal efficiency. Rectangular cavities are better than that of circular cavities. Parameters of SCC have been investigated by Lakshmipathy .B and Sivaraman. B, (13). Various lengths to diameter ratios have been experimented with a copper pipe diameter, which is commercially available in the market. They tested the SCC with changing the flow pattern as serpentine and parallel flow modes. For finding its optimal performance, the cavity cover shapes have been tested as rectangular and circular type covers. It has been concluded that the L/D ratio increases with the increase in water outlet temperature. Similarly, if the receiver diameter decreases means, the area of the cavity increases with a proportionate value.

SOLAR CAVITY CONFIGURATION

To improve and enhance the performance of FPC, a cavity has been introduced and this cavity structure improves the overall efficiency of the collector. Because of the cavity structure present inside the collector, the heat can be stored and

supplied to the working fluid for longer time duration. The multiple reflections of light energy passing into the cavity get induced because of the availability of heat inside the cavity. Thus it helps more effective heat exchange during late noon hours. Problems behind in the conventional flat plate collectors are they don't have the temperature stability. That is, fluctuations occur in exit temperature of water during part cloudy days.SCC gives a stable outlet water temperature even during part cloudy and cloudy days. The required / desired water exit temperature of SCC can be easily met out because of the adjustment in fluctuations is managed by the cavity itself and ensures the stable water outlet. Thus, no sudden drop in exit temperature of water may occur in SCC; adversely it occurs in the case of FPC. The cavity like configuration has been usually incorporated in concentrating type and Fresnel lens type solar collectors. To achieve a better performance and to develop the FPC, a cavity has been introduced and experimented. Figure 1 shows a simple view of a single cavity structure. Figure. 2 explains about how the process of multiple reflections happens inside the cavity. Also, it illustrates the cavity location/ position and transfer of heat energy from cavity to working fluid can be visually understood. The major components of a single cavity include 1.Receiver, 2.Aperture entry and 3.Supporting structure of the cavity. The imperatives and its functions of the major components are as follows:1. Receiver is used to collect and convert the heat energy into useful form. 2. Aperture is the one which has a small opening; through which the incoming solar radiation rays enters to the SCC. 3. The supporting structure is used to create a cover like structure and it holds the cavity. The solar radiation once enters inside the cavity gets multiple reflections by the cavity. Reflected light rays get absorbed by the receiver, and thus it heats up the working fluid. Some part of these incoming radiations may also escapes from it to atmosphere through the aperture entry. The dimensional and constructional details of the cavity collector are given in the table-1.

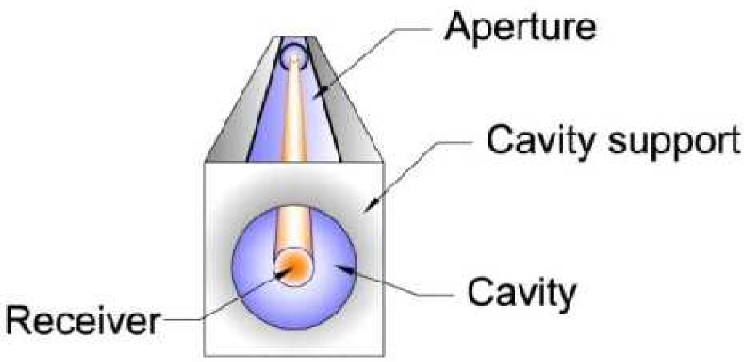

Figure 1: A Simple View of a Single Cavity Structure.

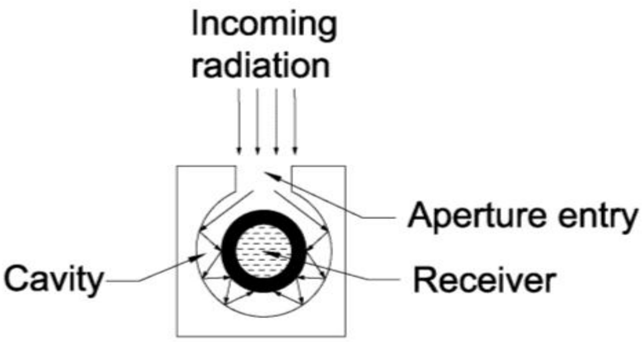

Figure 2: Process of Multiple Reflections Inside the Cavity.

Table 1: Constructional Details of SCC

Collector size	1.25 × 0.85 × 0.05 m
Cavity absorber material	Copper
Absorber coating	Industrial mat black paint
Area of each cavity	0.101 m^2
Thickness of glass plate	0.004m
Collector insulation	Glass wool
Number of cavities	5
Diameter of the tube	0.0127m

Figure 3 and figure 4 explains about the full dimensional details of SCC and schematic diagram of SCC, respectively. Similarly, figure 5 and 6 gives the inner dimensional details of plan view for SCC, respectively.

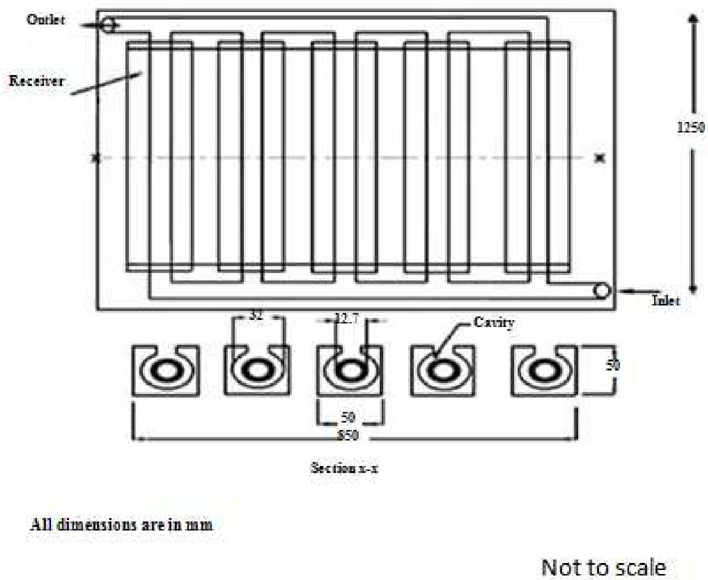

Figure 3: Details of Flat Plate SCC.

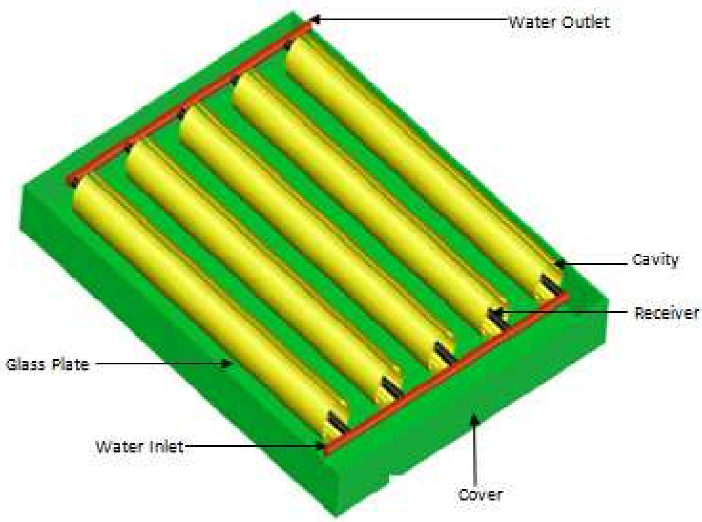

Figure 4: Schematic View of SCC with Single Receiver.

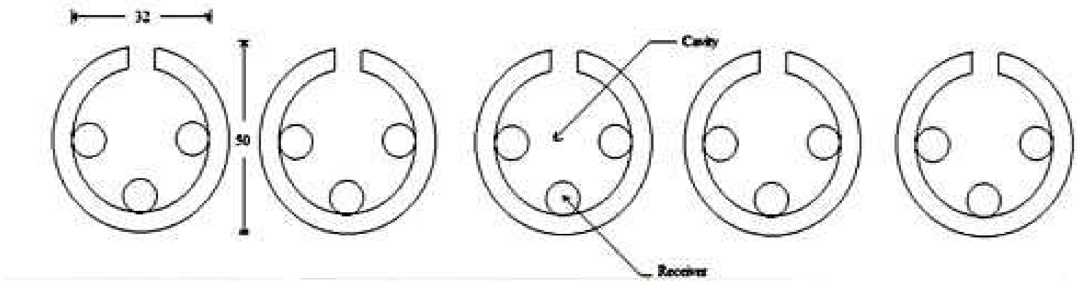

Figure 5: Details of Three Numbers of Receivers.

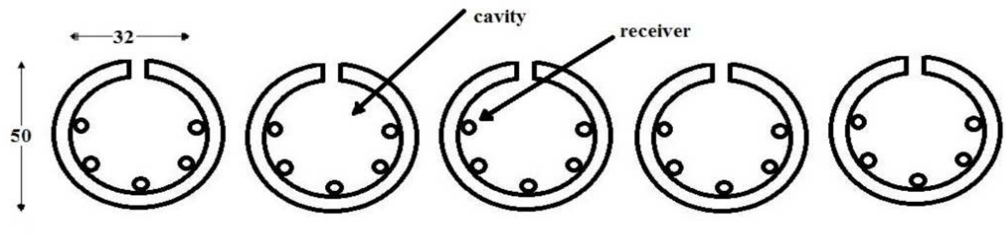

Figure 6: Details of Five Numbers of Receivers.

EXPERIMENTAL ANALYSIS

This section describes the experimental setup and the parametric analysis of the solar cavity collector, which includes the different types of receivers being used in SCC. A single cavity tube is made up of copper; cylindrical in shape and having 16 mm of radius. Similarly, five numbers of cavities has been fabricated and kept in square box with equal distance. An absorber, having a radius of 6.35 mm with industrial matt-black paint coated has been positioned concentrically within the cylindrical cavity.

All the inlet and outlet transport tubes are connected with parallel type connections. A glass plate mounted on the top serves as a shield to avoid the connective heat losses to the atmosphere. Also, it protects from the environmental effects like, rain, snow, etc. The outer metal box bottom and side joints are well sealed with glass wool insulation. The overall set up has been titled at an inclination of 11owith respect to the horizontal plane. Bottom most end of the SCC tubes are connected to the incoming water tank. Pyranometer instrument is used to measure the global radiation. Temperatures at different locations were measured by digital temperature indicator with the use of thermocouples. The ambient temperature was recorded using mercury thermometer. Thermocouples are located to measure the temperature of corresponding places like all cavities, inlet pipes, water outlet pipes and glass cover plate. The collector was kept in south side facing; open yard and exposed to sun. The experimentation has been done with a starting time from 9:30 A.M and ending time 5 P.M. The observations has been made on various days, and it was experimented with different water flow rates ranging from 0.002 kg/s to 0.0067 kg/s. SCC performance was investigated with copper receivers has been used inside the cavity. The observations were made for every 10 minutes interval of time.

RESULTS AND DISCUSSIONS

Usually, the cavity like receivers/collectors has been employed for concentrated high temperature solar applications. SCC has a greater advantage to hold heat because of its multiple reflectioning process happened inside the cavity. Moreover, proper designing of SCC makes increased capture of incoming solar radiation with more effectively. The

solar radiation, which has been absorbed by the SCC can withstand, hold and transport the heat to the working fluid which flows inside the receiver tubes. To utilize the space inside the cavity, the experimentation was made to modify the receivers as three and five numbers.

Figure 7. shows the efficiency graph for all types of receivers being used with respect to the time. Efficiency has been an increasing trend for single receiver, being used when compared to the other multi receivers. Maximum efficiency has been obtained as 65.51 % at 1 pm. Efficiency lies from 40 % to 60% in the case of single receiver setup, and while it has been 20% to 40% for other cases. For all the cases, efficiency is increase with respect to time.

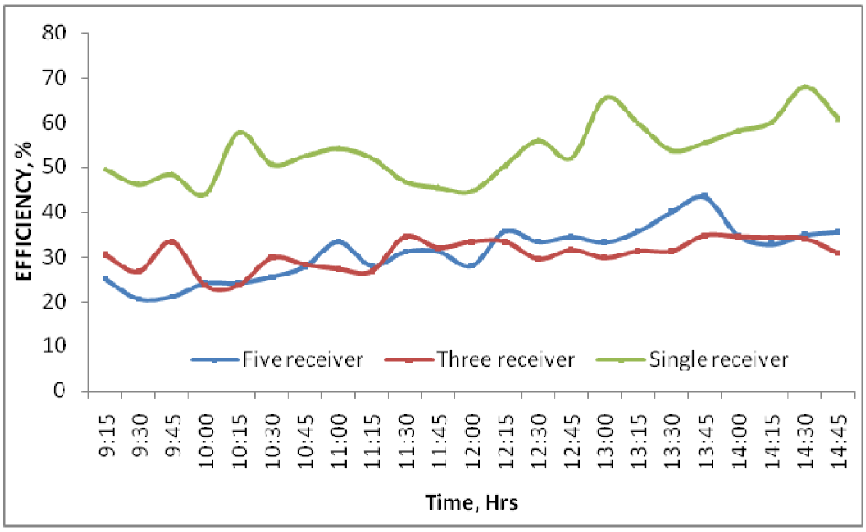

Figure 7: Time vs Efficiency Plot for Single, Three and Five Numbers of Receivers.

The variation in temperature changes, with respect to the cavity numbers for single and multi receivers being used is shown in figure 8. Five numbers of cavities has been used in SCC. To find out the optimal temperature, generated by the individual cavity for single and multi receiver setup has been shown in the figure. For single receiver setup, the maximum water exit temperature is 73oC recorded by cavity number one. For three numbers of receivers' setup, a maximum water outlet temperature is 69oC recorded by cavity number one. But, for five numbers of receivers records 60o C by the cavity number five.

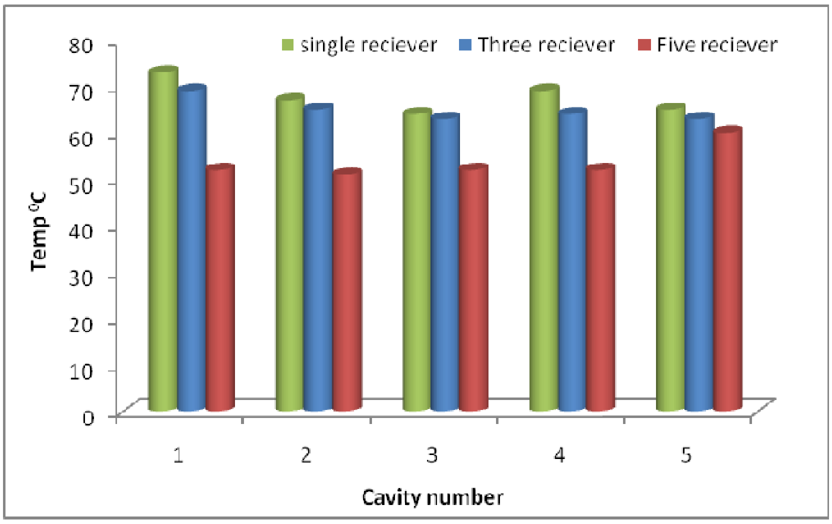

Figure 8: Distribution of Temperature vs Cavity Numbers for Single and Multi Receiver Setup.

Figure 9 shows time versus heat gained by the water for single and multi receivers' configuration. It is inferred from the figure, the water gains more amount of heat in single receiver setup when comparing to the multi receivers being used. The working fluid absorbs a heat value of 878.35 W in the case of single receivers' setup, which is the maximum amount of heat when compared to the other. The amount of heat gained by the water mainly depends on the cavity receivers being used. In general, if more numbers of receivers is used means, the heat gained amount should be more. But in SCC, the amount of heat gained inside the cavity is restricted by the number of receivers being used. Therefore, it is obvious to use a single receiver for the effective heat transfer flow between the collector and the working fluid (water).

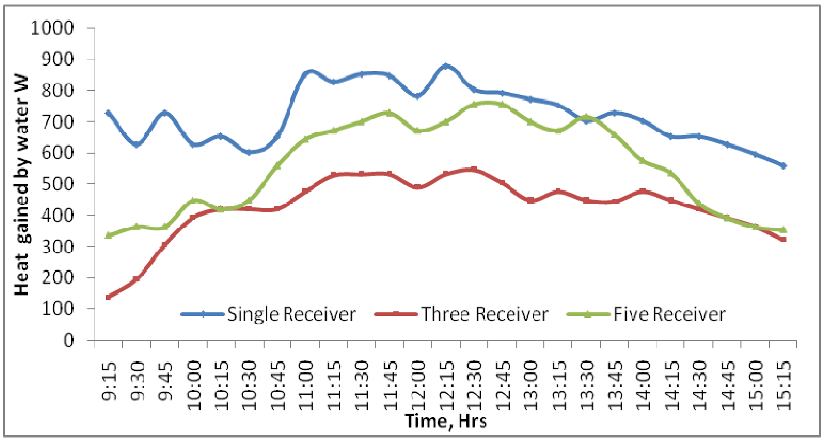

Figure 9: Distribution of Temperature vs Cavity Numbers for Single and Multi Receiver Configuration.

SUMMARY AND CONCLUSIONS

The main objective is to create a newer design, effective energy encapsulation, efficient heat exchange and higher heat withstanding capacity type configuration. Thus, the novel solution is a Cavity collector or receiver system. As we know about, the conventional flat plate collector does not work more efficiently and on the other hand, any one type of concentrating collectors that requires complicating sun tracking mechanisms and it can be more expensive too. Thus, it's simple to construct a cavity type configuration which has numerous advantages of both flat plate and concentrating type collectors. The cavity is a small air gap, provided circumferentially concentrated around the receiver tube. Many researchers have investigated about the cavity type configuration for the application of concentrating type collectors, but now it has been experimented on flat plate collector. It shows that there is a significant improvement in collector efficiency and also water outlet temperature. Proper design would increase the performance of the cavity collector better and better. Experimental work has been focused on to increase the efficiency and effectiveness of the collector. In afternoon hours, the radiation from the sun is gradually reduced. But the collector efficiency would not drop suddenly due to the cavity effect. Based on the experimentation, it has been inferred that the single cavity receivers is much better than that of multi receivers. The discussion made in previous chapter is as to provide the space inside the cavity, to make more efficient. But, if we go for more numbers of receivers, it would restrict the space inside the cavity resulting in reduction of cavity effects. Thus, the single receiver usage is recommended to use inside the SCC to entertain more heat transfer between the cavity and transport fluid.

NOMENCLATURE OF SCC

A	Collector Inclination angle to the horizontal plane , ^{o}
L	Length of the SCC, m
H	Height of the SCC, m
B	Breadth of SCC, m
T_{out}	Water outlet temperature, ^{o}C
L	Length of a single cavity tube, m
H	Height of a single cavity tube, m
$\dot{m}$	Water Mass flow rate, kg/s
H	Collector Efficiency, %
A_c	Area of the collector, m^2
I_t	Intensity of solar radiation, W/m^2

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ANNEXURE I

Figure 1: Photographic View of 3 Receivers Setup in SCC.

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